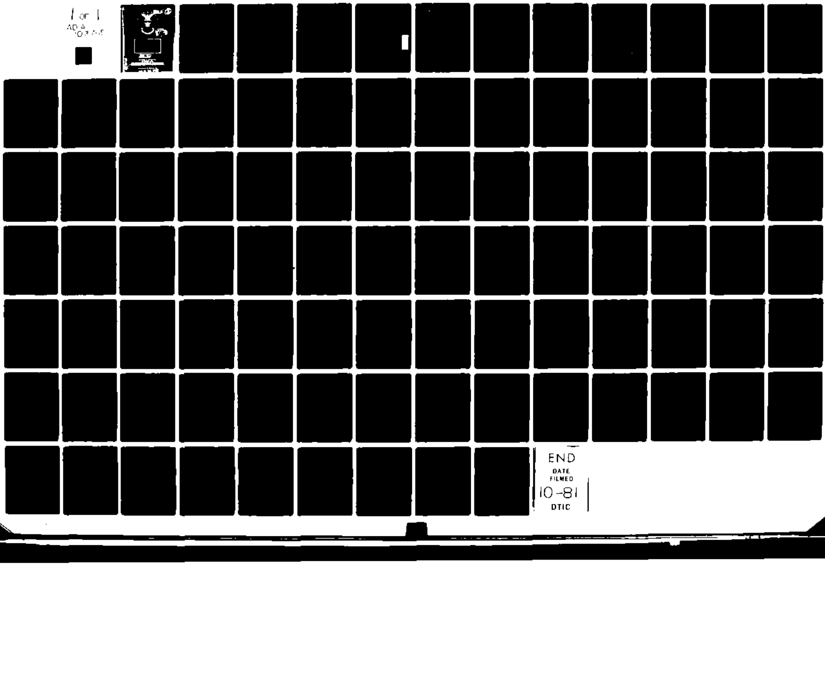
AD-A103 785 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 15/5
A PRESCRIPTIVE MODEL FOR RESOURCE ALLOCATION AT THE INTERMEDIAT--ETC(U)
JUN 81 E CONNOLLY, C D JOHNSON
UNCLASSIFIED AFIT-LSSR-26-81 NL

1 OF 1
AD A
103785



END
DATE
FILMED
10-81
DTIC

A PRESCRIPTIVE MODEL FOR RESOURCE ALLOCATION AT THE INTERMEDIATE LEVEL ENGINE FACILITY

Edward Connolly, Captain, USAF
Charlie D. Johnson, Captain, USAF

LSSR 26-81

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the Air Training Command, the United States Air Force, or the Department of Defense.

AFIT Control Number LSSR 26-81

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/LSH, Wright-Patterson AFB, Ohio 45433.

1. Did this research contribute to a current Air Force project?

   a. Yes   b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes   b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

   a. Man-years ________ $ ________ (Contract).

   b. Man-years ________ $ ________ (In-house).

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3 above), what is your estimate of its significance?

   a. Highly Significant   b. Significant   c. Slightly Significant   d. Of No Significance

5. Comments:

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

________________________ ________________________
Name and Grade   Position

________________________ ________________________
Organization   Location

FOLD DOWN ON OUTSIDE - SEAL WITH TAPE

FIT/ LSH
RIGHT-PATTERSON AFB OH 45433

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 73236 WASHINGTON D.C.

POSTAGE WILL BE PAID BY ADDRESSEE

AFIT/ DAA
Wright-Patterson AFB OH 45433

FOLD IN

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AFIT- REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR-26-81	2. GOVT ACCESSION NO. AD-A103785	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A PRESCRIPTIVE MODEL FOR RESOURCE ALLOCATION AT THE INTERMEDIATE LEVEL ENGINE FACILITY,		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward Connolly, Captain, USAF Charlie D. Johnson, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH, WPAFB OH 45433		12. REPORT DATE June 1981
		13. NUMBER OF PAGES 76
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 91		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

6 JUL 1981

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE AFR 190-17.

Fredric C. Lynch

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AIRCRAFT ENGINE REPAIR MODEL
BASE LEVEL ENGINE REPAIR
REPAIR PROCESS SIMULATION
RESOURCE ALLOCATION FOR ENGINE REPAIR
ENGINE SPARE PRODUCTION MODEL

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairmen: Mr. Daniel E. Reynolds, GS-13
Thomas Harrington, Major, USAF

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

012250

Inability to support spare engine requirements has a critical impact on this nation's ability to meet its worldwide commitments during a crisis. This study examined those factors that significantly affect the intermediate level Propulsion Branch's ability to provide a steady supply of spare engines. Through simulation modeling and analysis, four factors were identified as driving the Base Repair Cycle time: spare parts, repair equipment, manpower, and experience level. A decision support system was developed which enables model users to assess the influence on repair cycle time of additional funding levels in specific factor areas.

1473 A

LSSR 26-81

A PRESCRIPTIVE MODEL FOR RESOURCE ALLOCATION AT THE INTERMEDIATE LEVEL ENGINE FACILITY

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Edward Connolly, BS
Captain, USAF

Charlie D. Johnson, BS
Captain, USAF

June 1981

Approved for public release;
distribution unlimited

This thesis, written by

Captain Edward Connolly

and

Captain Charlie D. Johnson

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 17 June 1981

COMMITTEE CHAIRMAN

Thomas C. Harrington
COMMITTEE CO-CHAIRMAN

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks and appreciation to their wives, Chris and Brenda, for putting up with the deprivations they have endured for the last year. We also wish to thank our thesis advisors, Mr. Daniel E. Reynolds and Major Thomas Harrington, for their assistance and encouragement in completing this thesis. Also to Mrs. Phyllis Reynolds for her outstanding work in typing the final copy.

TABLE OF CONTENTS

Chapter		Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

BACKGROUND

Foreign policy is a means by which one nation informs other governments of its beliefs and commitments. Support of its allies and dedication to human rights are common foreign policy statements. However, sometimes there exists a difference between a nation's stated policy and those issues over which it is willing to risk confrontation. Consequently, it is the ability and desire to implement and enforce a nation's foreign policy that determines its influence with the rest of the world. The United States is an excellent example of a country that commands global influence because of its strong foreign policy and its ability to back up its commitments. Without this ability the United States would have very little influence thousands of miles away.

In order to remain a credible source of power, the United States must have the means to implement its policy objectives. A primary agency utilized in carrying out U.S. foreign policy commitments is the Air Force. The Air Force plays a major role in the deployment and resupply of men and equipment worldwide. It is easy to see then that the U.S. depends greatly on the Air Force to provide the means to enforce our foreign policy.

Within the Air Force, the Military Airlift Command (MAC) has the responsibility for all such strategic airlift. Consequently, this command is fully involved in any logistics effort. The 1973 Arab-Israeli War illustrates the essential role of MAC airlift in fulfilling the United States foreign policy commitments. After the first few days of the war it was only through the continued resupply of Israel by the United States, and the Military Airlift Command in particular, that the Israelis were able to continue (14:217,225). Thus, the strategic airlift role of MAC has a significant impact on the achievement of national level objectives.

In order to ensure that MAC maintains the ability to respond rapidly to any crisis, a great deal of emphasis is placed on sustained aircraft performance. Reliability becomes a major concern. If the equipment fails, or if replacement parts are unavailable when needed, the aircraft launches late; this could result in failure to attain a strategic goal.

One of the most critical systems on an aircraft is the engine. Rarely will an aircraft launch with a serious engine problem. This is especially true in MAC's case since any strategic airlift involves long flights over the ocean without intermediate stops. Obviously, then, the availability of replacement engines is essential for the successful accomplishment of airlift missions. When

an airlift effort causes a surge in flying hours and numbers of aircraft are required, *any shortage of replacement engines becomes a limiting factor in successful mission accomplishment.*

This limiting factor is a potential choke point which must be considered in any scenario involving increased flying hours and jet engine availability. For example, if a wing averages two engine failures per thirty missions flown, and the base engine repair facility can return an average of two and one-half engines per week to spare status (given that the wing averages thirty missions per week), then the requirement to surge in a wartime situation may increase the required number of engines beyond the facility's capability (1:27). Thus, the availability of spare aircraft engines can become the limiting factor or choke point in the deployment and resupply effort (1:27).

This problem, together with the high acquisition cost of engines, necessitates strict control of this asset (19:p.1-1). Control infers that the manager is aware of both the number of spare engines available and the average repair cycle time for any unserviceable ones. The flow of an engine in the repair pipeline is illustrated in Figure 1. After removal from the aircraft the engine is either sent to the depot or is repaired at the base level.

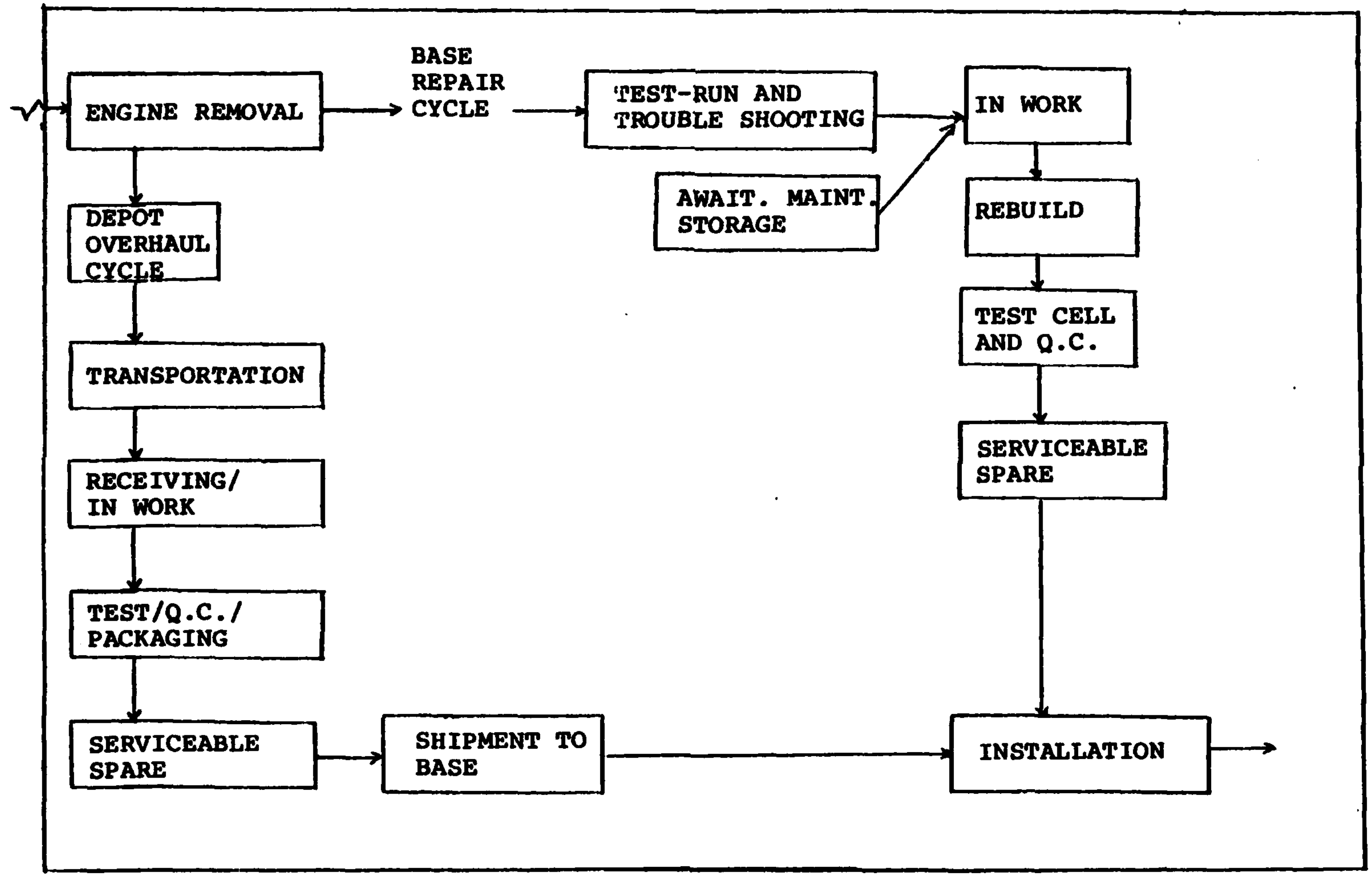


Fig. 1. Flow of Aircraft Engine in the Repair Pipeline (19:p.7-2)

This control of engine availability is essential in any logistics planning effort. The ability to accurately determine present engine availability and to forecast repair cycle time directly affects the accuracy with which contingency plans can be developed. Figure 2 relates engine demand to spare engine availability, and illustrates the critical need to be able to predict engine availability.

> At the start of war, demand for engines will jump instantaneously from peacetime to wartime rate, while mobilization of manpower and parts needed to support increased engine removals takes time [1:27].

Thus, as is shown in Figure 2, the ability to wage and sustain a conflict will depend on the resources available at the onset of a crisis and the ability to move rapidly to a wartime work level.

In order to forecast engine availability, knowledge of such factors as the operational environment, maintenance learning curve, and repair cycle time is required. For example, without an accurate forecast of the repair time it is extremely difficult to estimate whether the rate of engine repair will be sufficient to match wartime demand.

In view of this fact, plus the belief that any future conflict will be intense and of short duration, the Base Repair Cycle becomes the focal point for spare jet engine availabilty and, in particular, the Base Repair Cycle for the TF-33 P7/7A engine used on MAC's C-141 A/B aircraft.

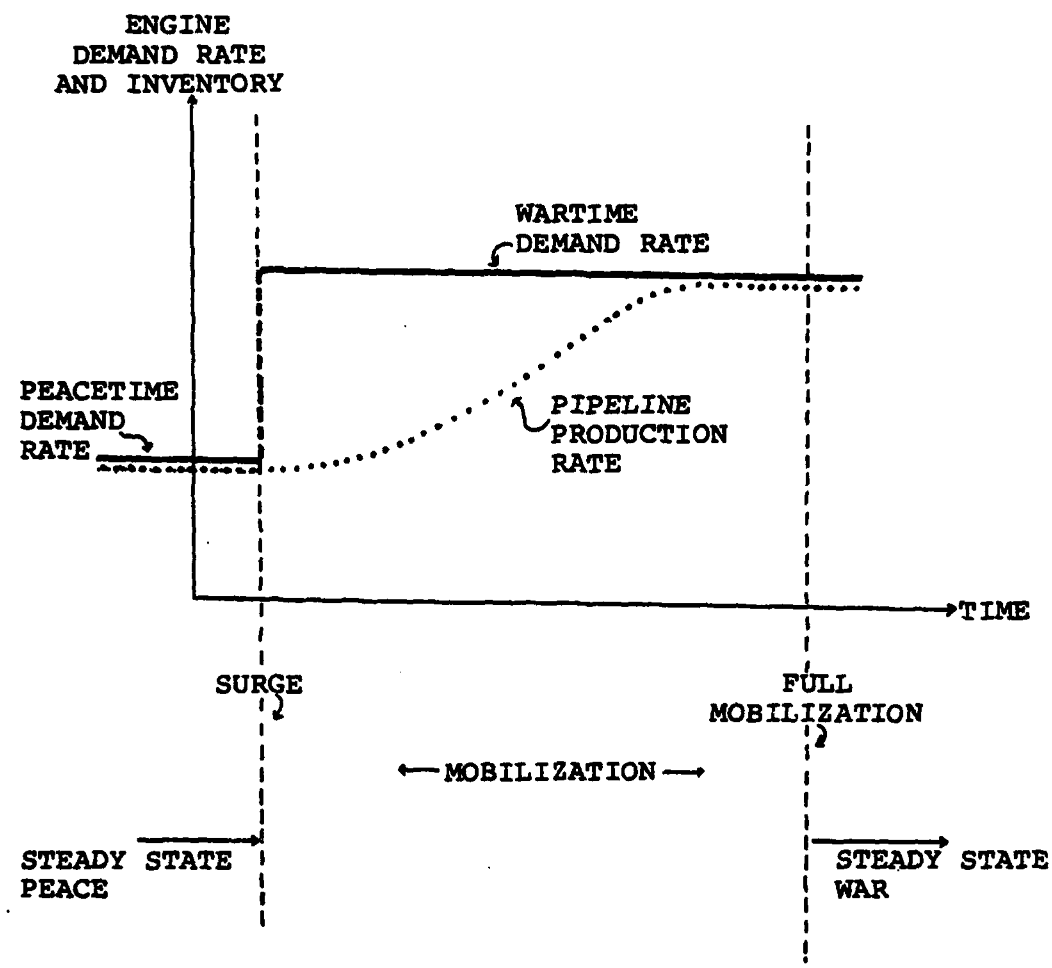


Fig. 2. Spare Engine Demand Versus Availability Function of Peace/Wartime Situation (1:29)

Purpose

This research was initiated based on the premise that the Base Repair Cycle time for the TF-33 P7/7A engine is a major factor in spare engine availability. The current standard used to measure a propulsion branch's engine repair performance was established by the Air Force Logistics Planning Board during the acquisition phase of the TF-33 engine. Unfortunately, this standard is inadequate because it assumes a smooth work flow from engine teardown, to repair, and finally engine buildup (3). In fact, repair times have consistently exceeded their estimates due to manpower shortages, loss of highly experienced mechanics, parts shortages, and the amount of repair equipment available. These discrepancies between actual repair time and the standard are shown in Table 1. The comparisons in Table 1 illustrate that no accurate estimate exists for the Base Repair Cycle, and support the problem statement of this research.

Problem Statement

No decision-making tool exists to aid the manager in his efforts to reduce the Base Repair Cycle time and thereby increase the level of spare engines. As a result, the engine manager at the base level is forced to make decisions concerning performance based on incomplete information on the effects of certain critical factors that

TABLE 1

AVERAGE BASE REPAIR CYCLE TIME FOR THE TF-33 P7/7A ENGINE AT MAC BASES (18:Part 1)

Base	Jul-Sep 79	Oct-Dec 79	Jan-Mar 80	Apr-Jun 80	Jul-Sep 80	AFM 400-1 Standard Repair Time
McGuire	51.9/40	32.2/59	67/39	69/35	69.3/68	22 Days
McChord	39.4/18	34.1/25	48.4/22	27.2/35	36.5/37	22 Days
Charleston	38.4/38	40.5/47	58.2/27	62.3/19	63.8/36	22 Days
Norton	45.6/31	36.1/53	64.7/40	59.8/46	63.9/77	22 Days
Travis	52.4/13	34.2/19	41.0/22	64.4/15	45.3/35	22 Days

Note: Numbers represent the average days to repair/number of engines repaired.

influence repair cycle time. This research identified these critical factors to be parts availability, amount of repair equipment available, average experience level of the engine mechanic, and the number of qualified mechanics available.

Consequently, the purpose of this research was to develop a decision support system that will aid the manager in estimating the Base Repair Cycle Time (RCT) for the TF-33 P7/7A engine. In order to determine if such a decision tool could be developed, the following question and research hypotheses were posed.

Research Question

Does the manager have a need for a decision-making tool that will allow him to choose among the different critical factor levels that affect repair cycle time, and that will help him determine the best mix of resource allocation needed to reduce the repair cycle time for jet engines?

Research Hypotheses

1. The standard used for the length of the Base Repair Cycle for the TF-33 P7/7A engine significantly differs from the actual time to repair.

2. There is a relationship between the length of the Base Repair Cycle for the TF-33 P7/7A engine and the critical factors which comprise it.

Objectives

The key objectives of this study were:

1. To develop a valid estimate for the length of the Base Repair Cycle for the TF-33 P7/7A engine.

2. To develop a decision support system which enables the engine manager to assess the influence on Repair Cycle Time of additional funding levels in specific factor areas.

Plan of the Report

To accomplish these objectives, Chapter II will examine the existing research efforts concerning engine repair, and then propose an alternate model for the engine Base Repair Cycle. Chapter III introduces the experimental design used to analyze the simulation output. Chapter IV develops the Resource Allocation Decision Matrix that is used in Chapter V to provide answers required by a hypothetical congressional request soliciting information about the impact a significant change in resource availability might have on the day-to-day operations of a typical engine maintenance facility. Chapter VI presents the conclusions and recommendations of this research effort.

CHAPTER II

MODEL DEVELOPMENT

Introduction

The purpose of this chapter is to explain the development of the model used in this research. First, we explore past research efforts in the area of Jet Engine Repair Cycle Time. Next, we analyze the information and assumptions needed to build our structural model. With this information, we then justify the selection of the site used to model a typical Base Repair facility. After explaining the method employed to identify the critical factors that impact Repair Cycle Time (RCT), the data sources used to develop estimates for the parametric model are discussed. This leads to an analysis of the factors that were used in building the structural model. Finally, we present the model built to simulate the Repair Cycle process at a TF-33 Jet Engine Repair Branch.

Past Research

Scarcity of resources, manpower shortages, equipment shortages, as well as the rising costs and complexity of propulsion systems are major constraints on MAC's ability to fulfill its operational mission. Because of these constraints, many planners have tried to identify

the critical factors that impact the Base Jet Engine Repair Cycle. We analyzed their efforts to recognize and propose possible solutions to this growing problem.

One of the first reports recognizing this need was done by HQ SAC (3). This report, "A Study of Spare Engine Repair Pipelines and Their Impact on Mission Capability," pinpointed the engine pipeline delay to "inaccurate prediction of repair rates for spare engines [3:iii]." The report also stated:

> The most significant problem appears when considering repair segments. Some (as reported in D024 products) are requiring two to three times allowed standards. This indicated that spare engines may not be adequate to meet flying requirements, since standard pipelines (vs. reported) are used in calculating engine requirements [3:ii].

The emphasis of this study was on the effect excessive repair times had on SAC's ability to surge in wartime. The report's conclusion was that repair times far exceeded the standard in peacetime, but would closely approximate it in a wartime situation. This is based on the use of unlimited numbers of persons working overtime and the expedient delivery of needed parts (2).

Another study which recognized the difficulty in estimating Repair Cycle Times for engines was done by Captain Ted C. Kehls entitled "An Analysis of Factors Influencing Spare Engine Management" (8). This research was mainly an overview of the problem areas which required attention in order to achieve more efficient resource use.

Two observations that were made are particularly relevant to this present research effort. First, the discrepancy in pipeline times across commands repairing the same engine reflects the unrealistic standard set for repair times (8:66). Second, the study emphasized that if a standard for engine repair time is to be established, then the minimum resources (manpower, equipment, parts, and training requirements) to perform up to that standard must be known. Both points reinforce the need to understand those critical factors that impact the base level Jet Engine Repair Cycle time. Again, this study presented an in-depth analysis of the problem, but stopped short of offering a solution.

The General Electric Corporation performed an analysis of the GE-12 15005 HP helicopter engine logistics support structure in 1973 in order to develop a logistics support model. This study, <u>Reliability, Maintainability, and Logistics Analysis</u> (17), researched reliability characteristics and maintainability factors of that engine in order to optimize the "entities" in the repair cycle. These "entities" are the number of aircraft assigned, the number of engines assigned, the engine components to be replaced, the maintenance actions required, the skill level and number of personnel required, and the equipment needed to perform the maintenance (17:47). The results of this study included a determination of the number of spare

engines needed to support a given level of helicopter operation. The computer model used could be altered to analyze the TF33 P7/7A engine, but the amount of data required on a large number of maintenance tasks precluded its use in this research.

AFLC has recently contracted with a research firm in order to improve engine pipeline analysis techniques. System Control, Inc.'s proposal Techniques for the Enhancement of Engine Pipeline Standards (1), states that the team of experts will concentrate on an effort to specify realistic, accurate pipeline standards (1:19). The focus of this contract, which will be completed in 1981, will be on the Depot Overhaul Cycle in particular, and on the ability of the engine repair facility in general, to surge during the initial phase of a conflict (1:27). The approach that the firm will take is to consider "measurement factors" in order to develop "pipeline standards" as fundamental elements of the engine pipeline (1:45). The term "measurement factor" is synonymous with the term "critical factor" used by this research team. Pipeline standards will encompass total times for repair, shipment, handling and removal/installation of the engine. While the focus of System Control's study, which concentrates on Depot Level maintenance, is different than that taken by this research effort, its findings may be useful in future research studies of the Base Repair Cycle.

Based on the results of this literature search, the authors concluded that no study exists which fully considers all of the critical factors that impact the base level jet engine repair process.

Preliminary Analysis

The premise of this research was that the Base Repair Cycle Time for the TF33 P7/7A engine is a major factor in spare engine availability. Failure to maintain a rapid repair capability has a direct impact on our combat readiness.

Data supplied by MAC Propulsion Branches indicate that the time to repair an engine at the base level is almost three times longer than the Air Force standard repair time of 22 days set forth in AFM 400-1. Statistical hypothesis 1 was developed to test whether the difference between the standard time and the actual time is statistically significant.

Statistical Hypothesis 1

H_0: The mean Base Repair Cycle Time for the TF33 P7/7A engine does not significantly differ from the AFM 400-1 standard.

H_1: The mean Base Repair Cycle Time is significantly higher.

The results of the test support the alternate hypothesis. Thus, it is concluded that the actual time to repair an engine at the base level is significantly longer

than the AFM 400-1 standard. (The actual test is included in Appendix A.) These results provide statistical support for this study.

Data Sources

The data used in this study were obtained from several sources. Historical data on Base Repair Cycle for all MAC Propulsion Branches is maintained at AFLC Headquarters in the D024 data system. Specific information concerning the repair function at McGuire was obtained through telephone interviews with the Propulsion Branch foreman.

Test Site Validation

McGuire AFB, New Jersey was the site selected for studying and modeling the Base Repair Cycle. It was chosen because of its role as Queen Bee[1] for the European theater, and because it is representative of all other MAC TF-33 Propulsion Branches.

McGuire's Propulsion Branch is responsible for engine repair on fifty-eight assigned C141 A/Bs. Consequently, the importance of McGuire's Propulsion Branch

[1]McGuire is designated as the central intermediate maintenance activity for all TF-33 P7/7A engine repair in the European theater of operation. It is tasked to assist in any repair effort on C-141s that experience engine problems throughout Europe. If the engine must be removed it is sent to McGuire to be repaired, and a replacement engine is sent by McGuire.

in many European efforts, made it a logical choice as a test site for use in this thesis.

Although AFM 66-1 requires that similar shop functions be present in all propulsion branches, subtle differences between branches can exist due to varying experience levels, flying commitments, failure rates, and/or management policies. In order to compare all propulsion branches in MAC, mean repair time was chosen as the performance indicator that would provide the most consistent measure of output. A statistical test was then conducted to test equality of the mean repair times.

Statistical Hypothesis 2

H_0: The engine repair process at McGuire is representative of all MAC Propulsion Branches.

H_1: A significant difference exists between McGuire and any one of the other MAC Propulsion Branches.

The results of the difference of means test (shown in Appendix A) supports the null hypothesis that McGuire's Propulsion Branch is representative of other MAC Propulsion Branches. This conclusion lent statistical support to the selection of McGuire as a test site and set the stage for the investigation of some of the factors that influence the operation of a MAC Propulsion Branch.

Critical Factor Identification

When an engine enters the Propulsion Branch, usually the first thing that is done is to send it to the test cell[2] in order to completely diagnose the malfunction. Then a determination is made whether to immediately work on the engine or to place it in a temporary awaiting maintenance (AWM) status. The AWM status is necessary when there is insufficient men or engine stands available to begin work; if the malfunction is extensive and will requirement a long repair period; or if parts are not available for the repair. Once work begins and the engine is torn down, the repair team will either completely repair the malfunction without any delays, stop to wait for delivery of needed parts, or stop work and put the engine into AWM status because the problem is more extensive than first diagnosed and major parts ordering is required. Once parts are obtained (which ranges from one to four man days) the work resumes on the engine. (The repair cycle is shown later in Figure 4.)

The length of time to complete the repair of the TF33 engine depends on the experience level of the team of mechanics performing the task. For instance, one point in the repair process where experience becomes a crucial

[2]The test cell is a separate facility colocated with the Propulsion Branch which has the capability to operate an engine off the wing of an aircraft.

factor, is the percent of engines which pass the maintenance test cell run on the first attempt. Consequently, when deciding what significantly impacts the Base Repair Cycle Time, consideration must be given to those variables which affect the repair of an engine as it moves through the various phases of work. The authors selected four variables as the critical factors affecting repair time. They are: parts availability, equipment availability, crew availability, and average experience level.

Parts availability, defined as the average percentage of the time that the base supply system had a part requested, was nominated as a critical factor because a lack of parts can delay an engine from proceeding directly into repair. Equipment availability, defined as the number of hardstands (engine work stands) available and operational at any one time, was selected as the second critical factor because a shortage of hardstands can limit the number of engines that can be placed in work and thus directly increase the Base Repair Cycle Time for an engine. Crew availability, defined as the number of teams of mechanics available for duty on any given day, can, like equipment availability, increase the repair time when it limits the number of engines that can be worked on. Experience level, the fourth critical factor, defined as the average number of years experience of Propulsion Branch personnel, was selected because the experience level of a

repair team has a significant impact on the time it takes to repair an engine.

In order to model the Base Repair Cycle, a few basic assumptions about the critical factors used in this research had to be made.

Critical Factor Analysis

One of the assumptions that must be made when selecting parts availability as a factor in the model concerns the adequacy of the indicator used to measure the level of parts availability. Several indicators exist at the base level which show the status of supply support, but the device needed for this research was one which gave a direct reflection of the impact of parts availability on repair time. The average percentage of time that the part was available from base supply within twenty-four hours requested was chosen because of its ability to demonstrate the impact of parts availability on engine repair time.

The second assumption that must be made concerns the relationship between repair time and the average experience level in the branch. This is the most difficult indicator to accurately quantify because the exact relationship between repair time and experience level is not known (4). For instance, is the relationship linear, exponential, or a combination? Research in this area is sparse, and several experts have contrasting opinions.

One expert's suggestion was to assume that the relationship is linear up to the time that the mechanic becomes a fully qualified five, seven, or nine level. This relationship is shown in Figure 3a. Figure 3b. relates the number of tasks learned to the skill level of the mechanic, and suggests that a mechanic learns a certain number of tasks until he is qualified at that skill level and then his performance remains constant. As he begins to progress towards his next skill level, the number of tasks learned again increases. This concept, however, ignores the problem of turnover rates in the engine mechanic field and in the military in general. If the mechanic changes duty stations, it is highly likely that the type of engine he repairs will change also.

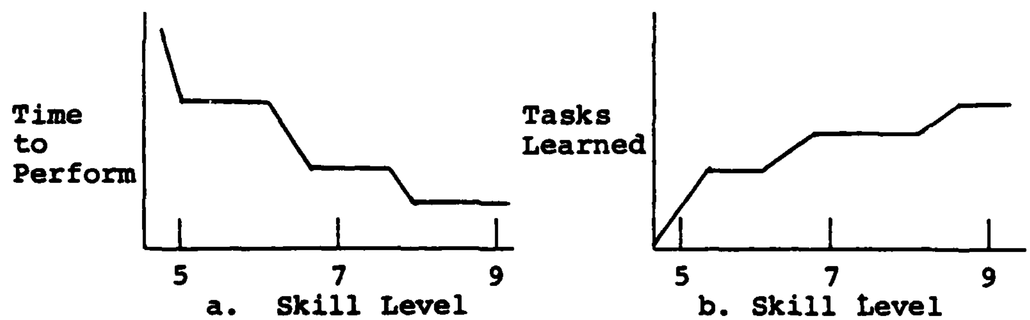


Fig. 3. Performance Versus Skill Level of Engine Mechanics

Another expert's opinion was to use a linear relationship in the absence of any other method (4). This suggestion was based on his extensive knowledge in the area

of modeling. Because of a lack of consensus, this research team felt that no conclusion could be made concerning the relationship between skill level and repair time.

This fact, together with the realization that the average experience level in a branch cannot be significantly changed in the short term, led the authors to develop an average experience level condition within the model. This condition was then held constant for all simulations.

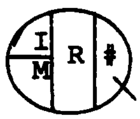
Another modification of the critical factors was necessary due to the interaction discovered during the simulation runs. The one-for-one combination of crews and workstands during engine repair made it apparent that a change in one was meaningless without a concurrent change in the other. Therefore, the number of crews and workstands were considered as a single critical factor for the purpose of model development, and will hereafter be referred to as "repair teams."

Model Development

The Q-GERT (Queueing-Graphical Evaluation Review Technique) modeling language was selected to model the repair process because of the power that is derived from its flexibility and ease of manipulation.

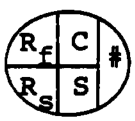
The Q-GERT model traces a transaction through the sequenced activities that it must undergo to be repaired. Statistics can be collected at certain nodes concerning cycle time of each activity and the number of transactions that have passed through the node. A brief description of the Q-GERT elements is presented and then the network model for the Base Repair Cycle is illustrated and discussed.[3]

Q-Node



I - initial # of transactions in the queue
M - maximum # allowed in the queue
R - ranking procedure for ordering in the queue
- node
Function - nodes at which transactions wait for service activities

Node



R_f - # of incoming transactions required to release the node
R_s - subsequent # required to release node
C - criterion for holding attribute set at node
S - statistics collections type

- deterministic branching
- probabilistic branching

Function - marks the arrival and departure of transactions as well as the start and stop of activities

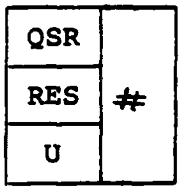
$\xrightarrow[\#\ N]{(P)(D,PS)}$

P - probability of taking that activity branch
D - distribution or function type
PS - parameter set #
N - # of parallel servers
- activity
Function - an operation/service performed on a transaction that could delay its progress through the network

---

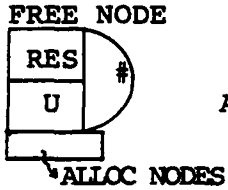
[3]All descriptions and definitions of Q-GERT terms were drawn from Modeling and Analysis Using Q-GERT Networks, by A. Alan B. Pritsker (13).

ALLOCATE NODE



QSR - queue selection rule
RES - resource type number
U - number of units to be allocated
- node number
Function - assigns available resources to transactions

FREE NODE



RES - resource type number to be freed
U - number of units to be freed
- node number
ALLOC - list of allocate node numbers to send freed resources back to
Function - allows resources to be made available to other transactions

Structural Model of the Repair Process

Figures 4 and 5 illustrate the structural model of the Base Repair Cycle. Node one in Figure 5 represents the start of the engine's flow through the branch. Two branches emanate from node one, the first representing the arrival rate of engines into the shop (activity one), and the second which shows the movement of the engine to an awaiting test cell run area (Q-node 2). At this point, the engine either waits for the test cell to become free, or it moves directly into the cell and is run (activity 3).[4] After the engine is run, a decision must be made whether to place the engine into awaiting maintenance status (AWM), or to allow it to proceed directly to the teardown

[4]The test cell run consists of operating an engine through the different conditions simulating the "on the wing" environment in order to isolate the problem.

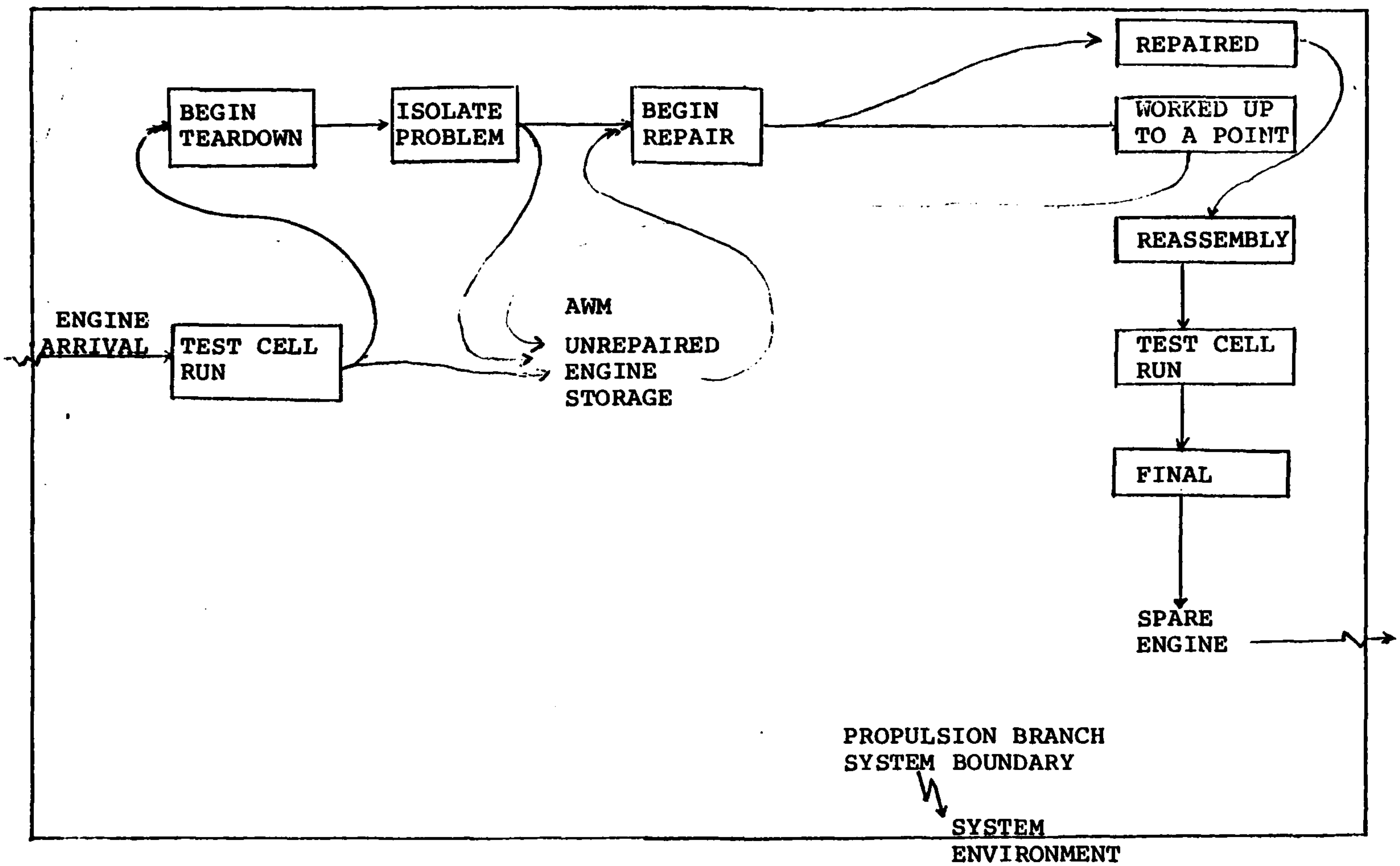


Fig. 4. Detailed Engine Flow in Base Repair Cycle

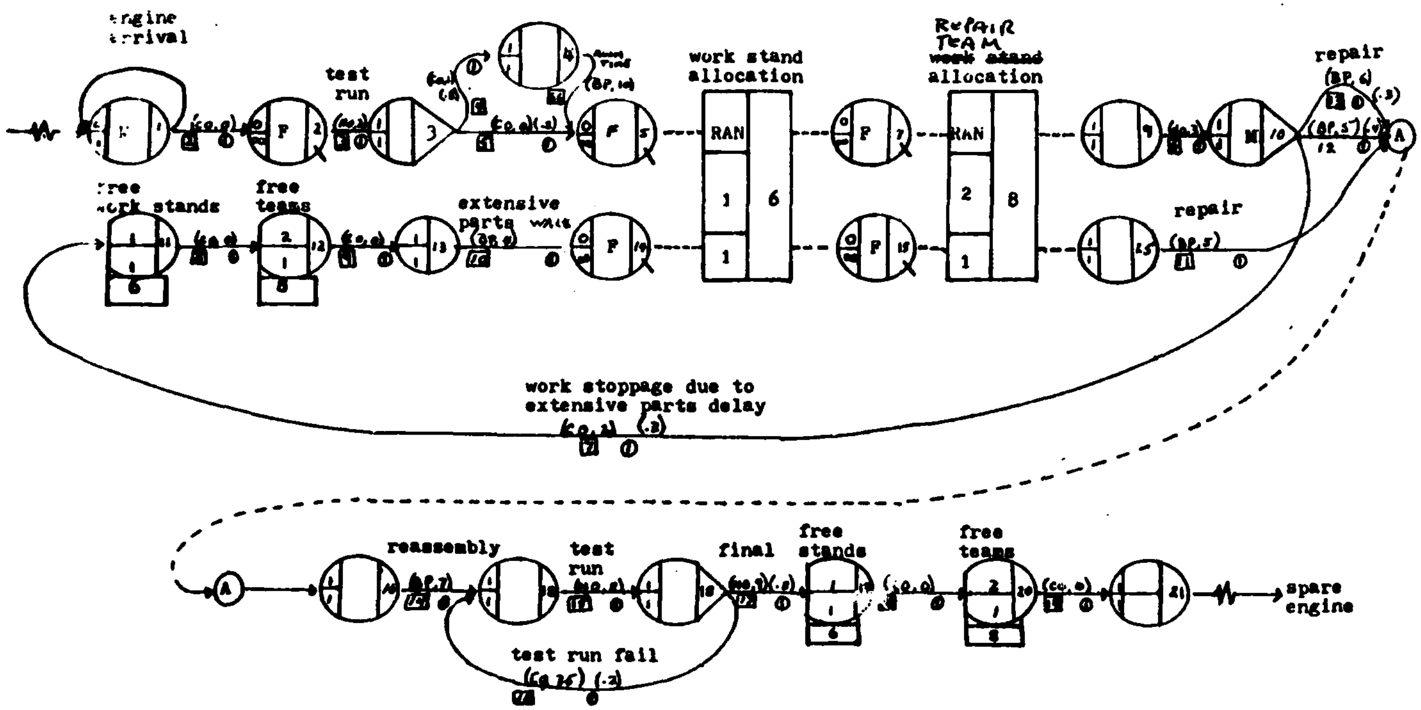


Fig. 5 Q-GERT Network Diagram for the Base Repair Cycle

phase. This decision is based on the extent of the repair required and whether or not the parts are available. The requirement for a decision is represented in the model by a probabilistic branch after node three. If the decision is made to place the engine into AWM status then activity four is taken to node four. Activity sixty-six, from node four to node five represents the actual time that the engine is in AWM status. After that time has elapsed, the engine arrives at node five. However, if the decision made was to place the engine directly into work, activity five is selected, and the engine moves immediately to Q-node five. The probabilistic nature of the decision at node three is handled by an input to the model which dictates the percentage of engines which will follow that branch. Node five represents engines that are ready to be worked on, but must wait until resources are allocated to them. The resources, workstands and teams of mechanics are allocated through nodes six and eight. An engine waits at node five for a workstand to become idle and then the resource allocation node (node six) assigns the stand to an engine based on the priority rule given the allocate node. For example, if the random priority rule was assigned to node six, then when a stand became free it would be assigned randomly to any engine waiting in node five. The random priority rule was used because it gives no consideration as to the length of time an engine has

been waiting, the nature of the malfunction, or any other attributes. This priority rule was chosen because it best models the actual decision process that the manager uses. For example, if the number of spare engines is at or below the minimum readiness level then the manager will choose to repair engines that can be repaired quickly and be added to the spare engine line. On the other hand, if the branch has sufficient spare engines to meet any contingency, the manager will most likely start work on engines that have major damage or will require a lot of maintenance to repair. After a workstand is assigned, the engine enters Q-node seven, where it goes through a similar process as it awaits assignment of a team of mechanics.

When the engine has been assigned both a team of mechanics and a workstand, it then moves to node nine, which represents the start of the engine teardown phase (activity six). Node ten marks the end of the teardown and the start of the repair phase. A three-way probabilistic branching occurs here that signifies that engine repair can follow three distinct patterns. First, repair of the engine could proceed smoothly, with all the parts available, and no further damage discovered than was diagnosed during the test cell run. This path is represented by activity twelve. Second, the repair could proceed smoothly, but experience minor delays while the team awaits additional parts from base supply (activity

thirteen). Third, the repair could proceed up to a point and then must be halted due to extensive parts ordering or because the extent of the damage to the engine was much greater than first diagnosed. This situation, shown by activity seven, dictates that the engine be placed in AWM status so that the resources (workstands and teams) are not tied up for months with an idle engine. Free nodes eleven and twelve represent the engine being taken off the workstand and the stand and team being freed for another awaiting engine (node five). Node thirteen signifies the beginning of the AWM time for the engine; while activity ten is the actual waiting time which could range up to several months. Once the part arrives or the determination is made to resume work, it moves to Q-node fourteen. This node, as well as Q-node fifteen, are equivalent to Q-nodes five and seven. The engine once again must vie for a workstand and team. Node twenty-five signals the start of the repair process for the engine now that it is ready once again to be worked on. Activity eleven represents this repair time which is set equal to activity twelve, a smooth repair with no additional delay. Once the engine has been repaired, it is ready to be reassembled. Node sixteen initiates the reassembly phase, and the activity label is number fourteen. After reassembly, the engine is required once again to be run in the test call in order to check the quality of the repaired engine

(activity fifteen). A probabilistic branching after the test cell run demonstrates the two possible outcomes of the run--success or failure. Activity sixteen is taken if the engine fails the test cell run. More repair must be accomplished on the engine before it can be rerun. If the engine successfully passes the test cell, then it proceeds into the final phase of work activity (activity seventeen). In this phase cosmetic and preventative maintenance are performed on the engine. Finally, nodes nineteen and twenty represent the freeing of the workstands and teams of mechanics as the engine becomes a serviceable spare.

Parametric Model

Figure 4 illustrated the structural model of the repair process at McGuire AFB. This is how an engine actually flows through the Base Repair Cycle and the numerous decision points associated with its repair. Information on the repair process at McGuire was acquired through research of existing data, interviews with the branch level managers and through personal experience. This aided in the quantification of the steps in the repair process. Thus the parametric model includes the parameters of the various activities and the percentage splits at the probabilistic branches. Table 2 lists the critical factors, shows their quantification, and transformation into model inputs. Without going step by step

TABLE 2

FACTOR LEVEL QUANTIFICATION

Critical Factors	Quantification	Numerical Value for Basic Model
Parts (Pa)	Average 70%≤Pa≤90%	Activity 11,12 BP Distribution Activity 13 BP Distribution Node three branching .8/.2 split Activity 7 extensive parts wait
	Best Pa>90%	
	Worst Pa<70%	
Equipment	Average 5≤stands≤12	Node three branching .8/.2 split Resource 1: # of stands available
	Best stands>12	
	Worst stands<5	
Manpower	Average 5≤crews≤11	Node three branching .8/.2 split Resource 2: # of crews available
	Best crews>11	
	Worst crews<5	
Experience Level	Average An average experience level was developed and maintained for all runs	Node three branching .8/.2 split Node eighteen branching .8/.2 Activity 12 BP Distribution Activity 6 NO Distribution Activity 14 BP Distribution

through the model, some of its unique features will be illustrated.

The time required to perform an activity (i.e., teardown, test cell run, etc.), is either represented by a constant or by a distribution. The two main distributions used in this model are the Normal distribution and the Beta Pert distribution. The Normal distribution was used to represent the test cell activity and the teardown activity, since research showed that the time to perform these functions was symmetrically distributed about their mean values. The repair, AWM time, and reassembly were represented best by the use of the Beta Pert distribution. This distribution recognizes the fact that most values cluster close to the node, but a few values are skewed so far right that the mean time is larger than expected. Figure 6 is a graph of the Base Repair Cycle time for a sample of thirty engines and clearly illustrates the appropriateness of the Beta Pert distribution.

The branchings at node ten are unique to this engine repair process. The three-way split after this node illustrates the three different repair situations that can occur. Forty percent of the engines entering the repair process have maintenance performed with no delays encountered (activity twelve). Thirty percent experience minor delays of less than one day while awaiting parts from base supply. Another thirty percent incur extensive waiting

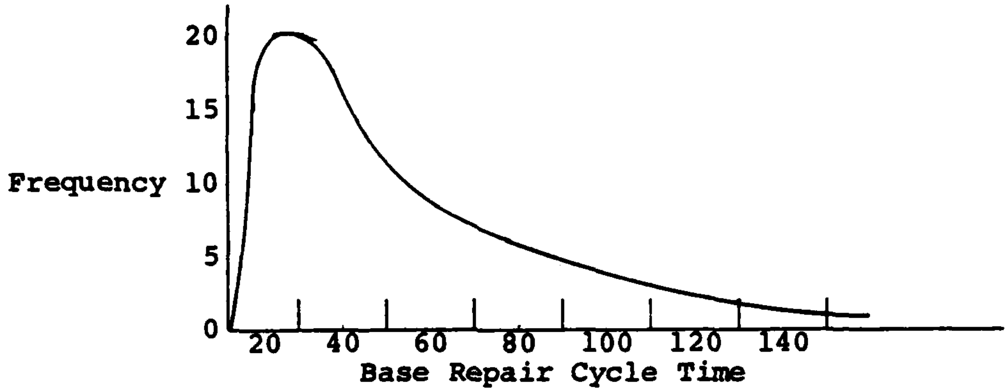


Fig. 6. Illustration of Beta Pert Distribution for Total Repair Time

time because a problem is found to be more extensive or the time for estimated parts delivery is excessive. Figure 7, a subset of the Q-GERT model, is included to illustrate this split.

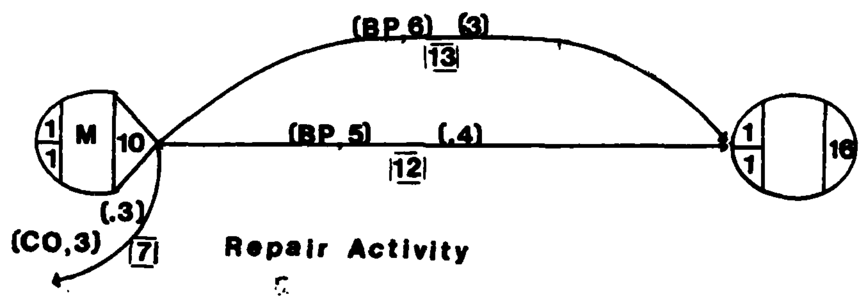


Fig. 7. Three-Way Probabilistic Branch

Performance Measures

While Q-GERT provides extensive output information for each run, the essential piece of information for the analysis and prediction portion of this research was time

recorded at node twenty-one, the mean engine repair time. This time represents the mean Repair Cycle Time obtained for a sample of 400 engines that moved through all phases of the repair process during one simulation run. An independent set of ten such times constituted a sample for a particular treatment required by the methodology of the experimental design used in the research effort.

Other output from the model was used for model verification and validation and will be discussed in the following sections.

Achieving Steady State

In order to validate the significance of the model results, the model must be operating at steady state when the analysis is performed. Shannon defines steady state as "a condition of regularity or stability in which opposing forces or influences are balanced [16:183]." The conditions to be balanced in this case are system underload versus system overload. The number of engines per run simulation must be large enough for the model to represent a typical state of the propulsion branch at any given time. System overload occurs when the number of engines arriving at any one time exceeds the number that can be repaired. Mr. Jess Ingram, an Air Force auditor working with the engine managers at Tinker AFB, told us that the trend in TF-33 engine repair is towards system overload (7).

Specifically, engines are arriving at an approximate rate of one a day, but due to shortages in the critical factors identified in this study (parts, repair equipment, manpower and experience level), and because the number of maintenance actions required often exceeds the number estimated, the repair time increases significantly. Consequently, engines arrive faster than they can be repaired. The result is a steadily increasing Base Repair Cycle time with the number of engines being processed through the Propulsion Branch.

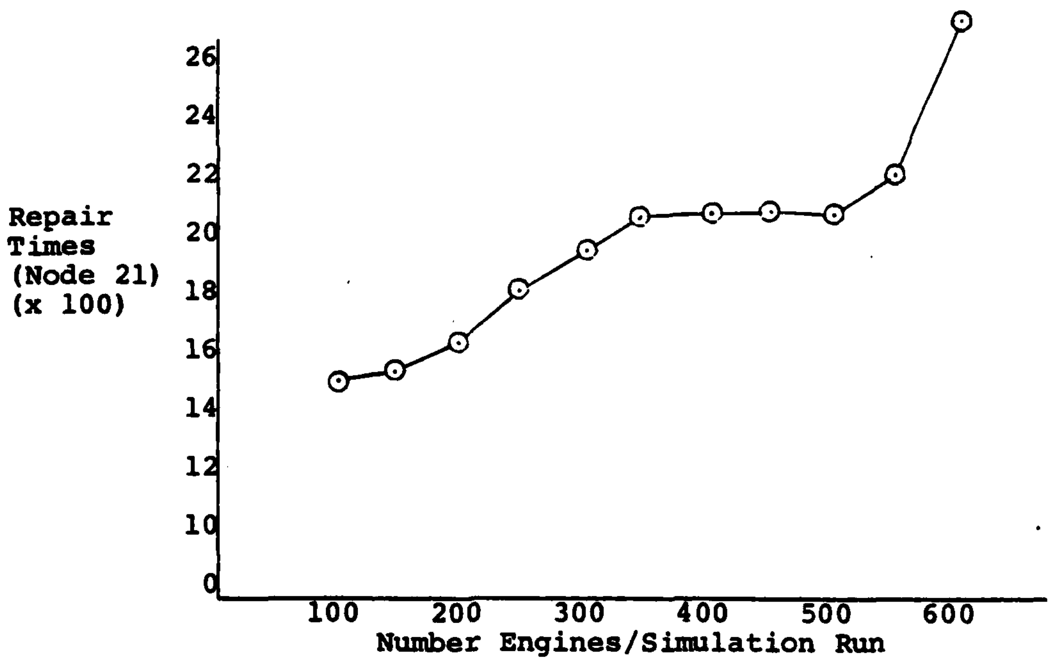


Fig. 8. Average Base Repair Cycle Time as a Function of the Number of Engines per Simulation

The purpose of running the model with varying numbers of engines was to identify the region in which the base repair facility operated at steady state. If capabilities of the branch are not fully utilized, the average repair time is lower than would normally be expected during everyday operation. This would be due to the slack resources on hand and the absence of any appreciable backlog of engines.

After the point where 300 engines passed through the branch, the curve began to flatten out. This was interpreted as the point at which all resources available were in use, and when any increase in the number of engines into the system would not affect Base Repair Cycle Time. This situation encompassed the interval from 325 engines to 500 engines per simulation. Based on this data, steady state for the model was defined as the point when 400 engines were processed through the branch. Achieving steady state is crucial because it ensures that any analysis of the output is based on a stable system.

As the number of engines increased beyond 500, the curve took a sharp upward turn. This condition represents system overload, and any analysis of output from this region would not have been relevant to this study. Once we knew that the output could be analyzed in a stable region, the next step was to validate and verify the actual model itself.

Model Verification and Validation

Verification was achieved through comparison of the output quantities with the parameters of the model. Two key indicators were examined to verify the model: probabilistic branching, and histograms for selected nodes. At node three a probabilistic branch occurs with an .80/.20 split designed in to represent the AWM/work decision. Examination of the Q-GERT output at 400 engines per simulation shows that the actual split is 80.04/19.96. A three-way split was designed into the model after node ten with a 30/30/40 split. The actual proportions were 28/29/43. Consequently, this indicator of model performance confirmed that the model was actually functioning as designed.

The second step in the verification process was to ensure that the distributions designed into the model were evident in the output. Figure 9 illustrates the histogram for the repair activity, beginning at node ten. Inspection of this histogram shows that the distribution of the output follows the Beta Pert Distribution which was input for that activity.

Interviews were conducted with field level engine supervisors to establish the credibility of the model developed from a user's point of view. Engine managers at McGuire AFB, AFLC Headquarters, and the TF-33 depot at Tinker AFB, agreed with both the structural and parametric model. The flow of the engine through the different phases

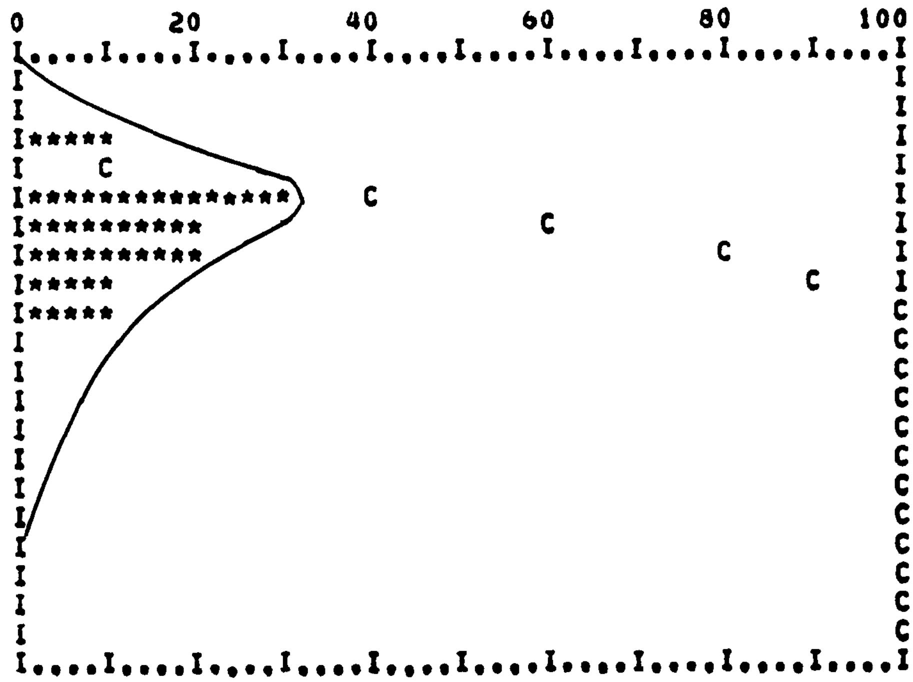


Fig. 9. Repair Time Histogram (Node 10)

of repair, and specifically the branching and queueing points, were all confirmed by these experts. The managers at McGuire were also consulted on the parametric model. Their advice and experience was used in the quantification of the critical factors and identifying most likely distributions. These same managers confirmed that the output from the steady state model was an accurate representation of the actual process. The changes to the Average Base Repair Cycle time were achieved by varying the levels of the critical factors, and again field level experts with the outputs from these runs to the point where they felt that the output was a logical conclusion for those inputs.

Statistical Hypothesis 3

H_0: The mean Base Repair Cycle time for the model does not significantly differ from the actual repair time at McGuire.

H_1: The mean repair time differs significantly from the actual repair time at McGuire.

There was insufficient evidence to conclude that the model's results were statistically different from the actual repair time at McGuire AFB. The significance of this test and the confirmation from several different experts verifies that the model is an accurate representation and validates the model results. Based on these findings, sensitivity analysis and prediction are justified.

The next chapter will develop the experimental design used to perform the sensitivity analysis on the critical factors.

CHAPTER III

EXPERIMENTAL DESIGN METHODOLOGY

Introduction

The purpose of this chapter is to develop a methodology which will be used to investigate how changes in critical factor levels impact Repair Cycle Time (RCT). First, the Analysis of Variance (ANOVA) model that was used to assess the effects of these factors is identified. Next, the key assumptions and specific tests of the model are introduced. Finally, the rationale for sample size selection and the procedures for generating the data required to assess the effect of various levels of resources on RCT are discussed.

ANOVA Model Identification

A two-factor, fixed effects, completely randomized model was selected as the most appropriate statistical model to use in order to assess the effect of various levels of parts availability and repair-team factors.[5] These factors are considered as the independent variables

[5]Fixed Effects--a fixed effects model is one in which the factor levels are predetermined by the researcher.

Complete Factorial Study--a study in which all possible combinations of the different factor levels were included (11:551).

in the analysis and are hypothesized to have a significant effect on Repair Cycle Time. Table 3 quantifies these factor levels.

TABLE 3

FACTOR LEVEL QUANTIFICATION

	Average	Best	Worst
Parts Availability	$70\% < Pa < 90\%$	$Pa \geq 90\%$	$Pa \leq 70\%$
Repair Teams	$5 < Crews < 11$ $5 < Stands < 12$	$Crews \geq 11$ $Stands \geq 12$	$Crews \leq 5$ $Stands \leq 5$

To determine what effect an average, worst and best level combination of these two factors would have on the repair process, we chose Repair Cycle Time as the most appropriate measure of performance; and hence, as the dependent variable for this analysis of variance.

Because the investigation focuses on two factors simultaneously, the ANOVA model becomes a multifactor investigation. In such a study, a *treatment* corresponds to some combination of factor levels. Since each factor in this analysis has three levels (average, best and worst), there are nine treatments. Figure 10 illustrates the factor level combinations that produce these nine treatments.

		A	B	W
		Parts Availability		
Repair Teams	A	T_1	T_2	T_3
	B	T_4	T_5	T_6
	W	T_7	T_8	T_9

Factors
1. Parts Avail.
2. Repair Teams

Factor Levels
(A) Average
(B) Best
(C) Worst

Treatments
$T_1, T_2, \ldots, T_9$

Fig. 10. Factor Level Combinations

Key Assumptions

The two-factor, fixed effects model assumes that:

1. The probability distribution associated with each treatment is normally distributed.
2. The probability distribution associated with each treatment has the same variance.
3. The observations for each treatment are random observations from the corresponding probability distribution and are independent of the observations for any other treatment [11:474].

To test for parts availability [factor (a)] main effects, for repair teams [factor (b)] main effects, and to test whether or not these two factors interact (AB), the two-factor ANOVA requires three hypotheses tests. These are listed below:

1. Test for Factor A Effects

   H_0: Repair Cycle Time is not affected by changes in parts availability.

   H_1: Repair Cycle Time is significantly affected by parts availability.

2. <u>Test for Factor B Effects</u>

H_0: Repair Cycle Time is not affected by changes in repair team levels.

H_1: Repair Cycle Time is significantly affected by changes in repair team levels.

3. <u>Test for (AB) Interaction</u>

H_0: No significant interaction occurs between the parts availability and repair team factors.

H_1: Significant interaction does occur between parts availability and repair team factors.

To ensure that the probability of rejecting a true null hypothesis was no larger than 5 percent (α), or the probability of committing such an error, was set at a level of .05. To determine if sample data produced by the model developed in Chapter II provided sufficient evidence to reject the null hypothesis and hence conclude that parts availability had an effect on Repair Cycle Time, or that repair team levels had an effect on Repair Cycle Time, or that the two factors significantly interacted, we asked SPSS to produce a p-value.

> When the p-value is so small that a sample result this extreme occurs only very rarely by chance phenomenon, the investigator can state that the data do not support the null hypothesis or that the result is significant. . . . If a number α is chosen as the cutoff point or level and the test result gives a p-value of p, the null hypothesis would be rejected if $p \leq \alpha$, and not otherwise [6:12,13].

As a result, we decided that if SPSS produced a p-value that was less than $\alpha = .05$, we would reject the null hypotheses of the three tests under investigation.

Sample Size Selection

Selecting an appropriate sample size for a two-factor study can be accomplished in several different ways. Shannon, in his book System Simulation: The Art and Science, indicates that as a general rule when running a factorial experiment, experimenters should use a sample size that will "keep the degrees of freedom for the error term at or above ten [16:164]." The next section of this chapter will reveal that by having the simulation generate ten replicates for each treatment of our two-factor model, we obtained eighty-one degrees of freedom for the error term, and hence are well above the minimum proposed by Shannon.

Data Collection

Table 4 lists the ten Repair Cycle Times produced by the repair process simulation for the nine possible combinations (nine treatments) of the parts availability and repair team factor levels. The treatment means are given at the bottom of the table and will be used in Chapter IV to construct the Resource Allocation Decision Matrix that provides the manager with the decision tool he needs to ensure an adequate level of spare engines exist to support MAC's strategic airlift requirements.

TABLE 4

MEAN REPAIR CYCLE TIME REPLICATES

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Parts	A_p	A_p	A_p	B_p	B_p	B_p	W_p	W_p	W_p
Repair Team	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}
1	779	685	930	770	690	797	970	800	1039
2	775	682	850	789	689	798	845	757	967
3	752	676	912	719	691	803	933	803	991
4	756	682	797	766	701	850	969	799	1023
5	743	677	799	812	661	792	886	807	955
6	775	713	901	706	690	823	930	807	951
7	812	700	857	745	703	801	917	808	1032
8	797	715	866	795	694	800	913	846	974
9	768	683	874	743	700	742	926	818	1135
10	739	677	868	777	695	785	936	811	1198
Treatment Means	770	689	865	757	691	801	922	806	1024

<u>Note</u>: A = Average; B = Best; W = Worst.

T_i, where i represents the i^{th} treatment i=1,...,9.

In order to produce the ten replicates for each of the nine treatments presented in Table 4, ten independent runs of the repair cycle simulation were executed, and each of ten mean Repair Cycle Times were recorded. These ninety mean values were then used by the SPSS subprogram ANOVA to test for factor effects and interaction and provide the information used to build the Resource Allocation Decision Matrix.

CHAPTER IV

DECISION SUPPORT SYSTEM FORMULATION

The purpose of this chapter is to review the results of the two-factor ANOVA introduced in Chapter III, and to build a Resource Allocation Decision Matrix (RADM) based on these results. Output from the SPSS subprogram ANOVA is analyzed and results from this analysis are then used to generate the statistical information required to construct the matrix.

ANOVA Output Analysis

The SPSS subprogram was asked to analyze the nine sets of treatment replicates (mean Repair Cycle Times) given in Table 4, and produced the ANOVA table displayed in Table 5.

As indicated in Chapter III, the two-factor fixed effects model assumes that:

1. Each of the probability distributions is normal.

2. Each probability distribution has the same variance.

3. The error terms are both independent and normally distributed.

TABLE 5

ANOVA OUTPUT

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	915679.467	4	228919.867	157.367	.001
PARTAVL	491065.867	2	245532.933	168.787	.001
REPAIRTM	424613.600	2	212306.800	145.946	.001
2-Way Interactions	31356.133	4	7839.033	5.389	.001
PARTAVL REPAIRTM	31356.133	4	7839.033	5.389	.001
Explained	947035.600	8	118379.450	81.378	.001
Residual	117830.000	81	1454.691	-	-
Total	1064865.600	89	11964.782	-	-

TABLE 5--Continued

Group	Count		Stand. Dev.	Stand. Error	Min.	Max.	95 Percent Conf Int for Mean
GRP 1	10	769.60	23.18	7.33	739.00	812.00	753.02 to 786.18
GRP 2	10	689.00	14.83	4.69	676.00	715.00	678.39 to 699.61
GRP 3	10	865.40	43.57	13.78	797.00	930.00	834.23 to 896.57
GRP 4	10	756.70	32.71	10.35	706.00	812.00	733.30 to 780.10
GRP 5	10	691.40	11.81	3.73	661.00	703.00	682.95 to 699.85
GRP 6	10	801.10	23.03	7.28	762.00	850.00	784.63 to 817.57
GRP 7	10	922.50	36.88	11.66	845.00	970.00	896.12 to 948.88
GRP 8	10	805.60	21.78	6.89	757.00	846.00	790.02 to 821.18
GRP 9	10	1024.10	82.84	26.20	931.00	1194.00	964.84 to 1083.36
TOTAL	90	813.93			661.00	1194.00	
UNGROUPED DATA			109.39	11.53			791.02 to 836.84
FIXED EFFECTS MODEL			38.14	4.02			805.93 to 821.93
RANDOM EFFECTS MODEL			108.80	36.27			730.30 to 897.57

RANDOM EFFECTS MODEL - ESTIM. OF BETWEEN COMPONENT VARIANCE 11692.4759

TESTS FOR HOMOGENEITY OF VARIANCES

COCHRANS C = MAX. VARIANCE/SUM(VARIANCES) = .5241, P = .000 (APPROX.)

BARTLETT-BOX F = 6.440, P = .000

MAXIMUM VARIANCE / MINIMUM VARIANCE = 49.234

We know from the Central Limit Theorem, "For almost all populations the sampling distribution of $\bar{x}$ is approximately normal, when the simple random sample size is sufficiently large [12:202]." Therefore, since the values used as replicates were mean Repair Cycle Times derived from a sample size of 400, we assumed that each probability distribution is normal. Although the Cochran's Test indicated that we should reject the hypothesis that each treatment probability distribution has the same variance, it can be shown that, "If the error variances are unequal, the F-test for the equality of means with the fixed effects model is only slightly affected [11:514]." Fortunately, because Q-GERT produces independent observations, we were able to conclude that the observations for each treatment are random observations from the corresponding probability distribution, and are independent of the observations for any other treatments.

Once the assumptions of the two-factor model had been addressed, the ANOVA output presented in Table 5 was analyzed, and clearly indicated the parts availability (PARTAVL), and the repair teams main effect (REPAIRTM), with p-values of .001, were statistically significant at the α = .01 level. Additionally, their two-way interaction, with a p-value of .001, was statistically significant. Thus we can reject the null hypotheses:

H_0: Repair Cycle Time is not affected by changes in parts availability;

H_0: Repair Cycle Time is not affected by changes in repair team levels;

H_0: No significant interaction occurs between parts availability and repair team levels;

and conclude

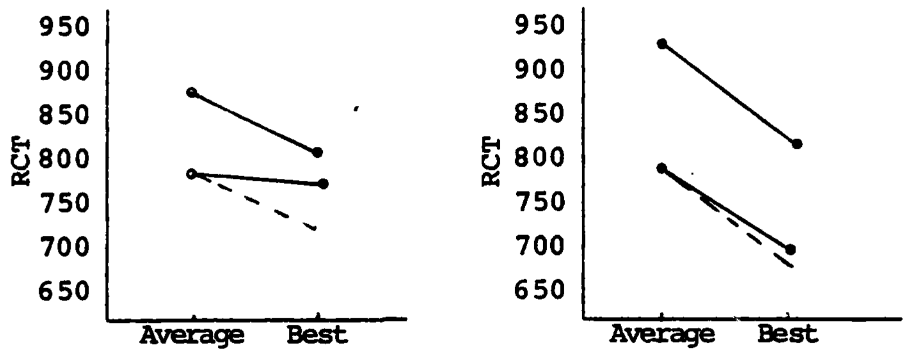
1. Changes in the level of parts availability or changes in the repair team levels have a significant effect on cycle time achieved by the repair process; and

2. A significant difference between the mean Repair Cycle Times will be observed for any two levels of parts availability as we move from one level of repair teams to the next or, conversely, that we will observe a significant difference between the mean Repair Cycle Times for any two levels of repair teams as we move from one level of parts availability to the next.

Figure 11 graphically displays this interaction phenomenon for the AB factor level combination. Interaction is indicated because the factor level curves in the graph fail to remain parallel as they move across the factor levels plotted on the ordinal axis. This is clearly the case in both graphs plotted in Figure 11.

Resource Allocation Decision Matrix Development

Because the ANOVA table indicated that significant interactions existed, the Tukey's Multiple Pairwise Comparison Test was used to:



$A_pA_{RT} = 770$
$A_pW_{RT} = 865$
$B_pA_{RT} = 757$
$B_pW_{RT} = 801$

$A_pA_{RT} = 770$
$W_pA_{RT} = 922$
$A_pB_{RT} = 689$
$W_pB_{RT} = 806$

Note: The dotted lines indicate how the changes would have been had there been no interaction.

Fig. 11. Critical Factor Interaction

1. Estimate the difference between all possible pairs of treatment means;

2. Determine if the difference between any particular pair of treatment means was statistically significant; and

3. If significant, whether the difference represented a positive or negative shift in the mean Repair Cycle Times.

This procedure allowed us to obtain the information needed to construct the Resource Allocation Decision Matrix.

Tukey Multiple Pairwise Comparison

To accomplish the Tukey Multiple Pairwise Comparison, the nine treatment means reported in Table 4 of Chapter III were rank ordered and plotted on the real number line as shown in Figure 12.

689	691	757	770	801	806	865	922	1024

Fig. 12. Rank Order of RCT Means

A comparison involving any pair of means was declared to be significant if their difference exceeded the following Tukey's Honestly Significant Difference test statistic, defined by:

$$HSD = q(\alpha, v)\sqrt{MSE/n} = 5.21\sqrt{\frac{1454.6}{10}} = 65$$

where,

v = the degrees of freedom for the Mean Square Error = 9;
α = level of significance = .01;
n = the number of observations for each treatment level (assuming all treatment sample sizes are equal); and
MSE = Mean Square Error from ANOVA output in Table 5.

To construct Table 6, the Resource Allocation Decision Matrix, we implemented the following procedure:

Step 1. The mean difference between all possible pair combinations was computed, and the sign noted;

Step 2. The absolute difference was compared to the HSD statistic to determine if it constituted a significant difference; and

TABLE 6

RESOURCE ALLOCATION DECISION MATRIX (RADM)

Parts	A_p	A_p	A_p	B_p	B_p	B_p	W_p	W_p	W_p
Repair Team	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}
A_pA_{RT}	-	$81_{S\uparrow}$	$95_{S\uparrow}$	NS	$81_{S\downarrow}$	NS	$152_{S\uparrow}$	NS	$254_{S\uparrow}$
A_pB_{RT}	$81_{S\downarrow}$	-	$176_{S\uparrow}$	$68_{S\downarrow}$	NS	$112_{S\uparrow}$	$233_{S\uparrow}$	$117_{S\uparrow}$	$335_{S\uparrow}$
A_pW_{RT}	$95_{S\downarrow}$	$176_{S\uparrow}$	-	$108_{S\downarrow}$	$176_{S\downarrow}$	NS	NS	NS	$159_{S\uparrow}$
B_pA_{RT}	NS	$68_{S\uparrow}$	$108_{S\uparrow}$	-	$68_{S\downarrow}$	NS	$165_{S\uparrow}$	NS	$267_{S\uparrow}$
B_pB_{RT}	$81_{S\uparrow}$	NS	$176_{S\uparrow}$	$68_{S\uparrow}$	-	$112_{S\uparrow}$	$233_{S\uparrow}$	$117_{S\uparrow}$	$335_{S\uparrow}$
B_pW_{RT}	NS	$112_{S\downarrow}$	NS	NS	$112_{S\downarrow}$	-	$121_{S\uparrow}$	NS	$233_{S\uparrow}$
W_pA_{RT}	$152_{S\downarrow}$	$233_{S\downarrow}$	NS	$165_{S\downarrow}$	$233_{S\downarrow}$	$121_{S\downarrow}$	-	$116_{S\downarrow}$	$102_{S\uparrow}$
W_pB_{RT}	NS	$117_{S\downarrow}$	NS	NS	$117_{S\downarrow}$	NS	$116_{S\uparrow}$	-	$218_{S\uparrow}$
W_pW_{RT}	$254_{S\downarrow}$	$335_{S\downarrow}$	$159_{S\downarrow}$	$267_{S\downarrow}$	$335_{S\downarrow}$	$335_{S\downarrow}$	$108_{S\downarrow}$	$218_{S\downarrow}$	-

$S\downarrow$ = Significant decrease in Repair Cycle Time (RCT).
$S\uparrow$ = Significant increase in Repair Cycle Time (RCT).
NS = Not significant 0 to 64 hours change in RCT.
A_p = Average parts.
A_{RT} = Average repair team.
B_p = Best parts.
B_{RT} = Best repair team.
W_p = Worst parts.
W_{RT} = Worst repair team.

Step 3. If a difference was significant, it was placed in the appropriate cell with a subscript of $S\downarrow$, $S\uparrow$, which should be interpreted as implying a significant decrease or increase in RCT; if the difference was not significant, an NS was placed in the appropriate cell.

Although the table contains point estimates for Repair Cycle Times, managers may be interested in obtaining information about the precision of the estimate. Fortunately, the Tukey Multiple Comparison procedure provides multiple comparison interval estimates for any or all pairwise comparisons between two treatment means. For example, if a manager is contemplating going from $W_p A_{RT}$ to $B_p B_{RT}$ combination, using Table 6 he observes the difference is 233. He can also determine that with 95 percent confidence the true mean difference lies between 179 and 287.[6]

In Chapter V, a scenario will be developed that demonstrates that objective two of this research effort (to develop a decision support system which enables the engine manager to assess the influence on Repair Cycle Time of additional funding levels in special factor areas) has been achieved.

---

[6] $D-T_s(D) \leq \mu_{ij}-\mu_{i'j'} \leq D+T_s(D) \qquad i,j \neq i',j'$

where:

$D = \bar{Y}_{ij.}-\bar{Y}_{i'j'.}$

$s^2(D) = 2MSE/n$

$T = \frac{1}{\sqrt{2}}\, q(1-\alpha; ab, (n-1)ab)$

CHAPTER V

PREDICTION

This chapter provides a scenario which demonstrates the value of the Decision Support System (DSS) introduced in Chapter IV. Its significance as a management tool is discussed as we examine the management decision process involved in responding to a congressional inquiry regarding the effect increased funding for resources might have on the engine repair proces.

Scenario

Because of the outcome of the past presidential election, many areas of national defense are slated to undergo major changes. One change that will have a significant impact on the area of logistic support is the upgrading of our ability to respond to a crisis anywhere in the world.

One method of increasing the logistic support to our forces is to increase the amount of spare parts that will be funded in the upcoming budget. But, in order to authorize the monies needed to purchase these spare parts, Congress will want to know how it will affect the overall ability of the units to accomplish their mission.

So, the question becomes--*How will an increase in the percentage of available parts affect a unit's operation?*

If Congress decides to increase the percentage of parts available for jet engine maintenance, one of the first things they will do is to equate the amount of money being made available to a percentage increase in parts availability.

For example, if Congress decided that it would increase spare parts funding by, say, 50 million dollars, this might be equated to a 10 percent increase in the level of parts availability Air Force-wide. This would be comparable to going from an A_pA_{RT} to a B_pA_{RT} position as defined by this study in Chapter IV. Therefore, the manager has to be able to quickly and accurately provide information with regard to how Repair Cycle Time is affected by changes in those critical factors discussed in this research.

First, the manager would review the structural model that is provided in Chapter II. If it represents his current operation, he might only change the parameters representing those conditions he is presently experiencing. After this, he would then obtain simulation output similar to that displayed in Table 7. The information that is of use to him is found under the node twenty-one statistic which shows that the average Repair Cycle Time is 747.6 hours. He would use the information from ninety such

TABLE 7

NODE 21 STATISTICS

SIMULATION PROJECT TF33
DATE 3/ 21 81

RESULTS FOR RUN 1

NODE	AVE.	NO. OF OBS.	TYPE OF STATISTICS
21	747.5850	400.	1

NUMBER IN Q-NODE / ** WAITING TIME ** IN QUEUE

NODE	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
2	0.0004	0.	2.	0	0.0343
5	3.3399	0.	13.	2	266.7705
7	0.6122	0.	2.	1	49.1444
14	1.0358	0.	15.	1	257.2410
15	0.1878	0.	2.	0	47.0004

SERVER UTILIZATION

SERVER	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
3	1	0.0606	146.0000	13.7663

simulation runs to supply data to the two-factor analysis of variance test.

With this information, the manager could now perform the Tukey Honestly Significant Difference test statistic. That would let him know what changes in the Repair Cycle Time were significant. Next he would construct the Resource Allocation Decision Matrix (RADM) (Table 8) and use this table to accurately make predictions about changes in the Repair Cycle Time induced by variations in the level of the critical factors that affect his operation.

The manager would enter the RADM Table 8 from the left at the A_pW_{RT} row. Moving to the right, and anticipating an increase in parts to B_p he would stop under the B_pA_{RT} column which shows a significant decrease in Repair Cycle Time of 108 hours or approximately seven days. This decrease of seven days would mean more engines could be processed in a shorter period of time. This also implies that there would be more spare engines available for the planners to allocate for the support of any surge effort.

The manager can now answer the question, *How will a given percentage change in parts availability affect the Repair Cycle Time for his operation?* In this case, the manager could report that with a 10 percent increase in parts availability, there would be a seven-day decrease in the average Repair Cycle Time for a TF-33 jet engine.

TABLE 8

RESOURCE ALLOCATION DECISION MATRIX (RADM)

Parts	A_p	A_p	A_p	B_p	B_p	B_p	W_p	W_p	W_p
Repair Team	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}	A_{RT}	B_{RT}	W_{RT}
A_pA_{RT}	-	$81_{S\uparrow}$	$95_{S\uparrow}$	NS	$81_{S\downarrow}$	NS	$152_{S\uparrow}$	NS	$254_{S\uparrow}$
A_pB_{RT}	$81_{S\downarrow}$	-	$176_{S\uparrow}$	$68_{S\downarrow}$	NS	$112_{S\uparrow}$	$233_{S\uparrow}$	$117_{S\uparrow}$	$335_{S\uparrow}$
A_pW_{RT}	$95_{S\downarrow}$	$176_{S\uparrow}$	-	$108_{S\downarrow}$	$176_{S\downarrow}$	NS	NS	NS	$159_{S\uparrow}$
B_pA_{RT}	NS	$68_{S\uparrow}$	$108_{S\uparrow}$	-	$68_{S\downarrow}$	NS	$165_{S\uparrow}$	NS	$267_{S\uparrow}$
B_pB_{RT}	$81_{S\uparrow}$	NS	$176_{S\uparrow}$	$68_{S\uparrow}$	-	$112_{S\uparrow}$	$233_{S\uparrow}$	$117_{S\uparrow}$	$335_{S\uparrow}$
B_pW_{RT}	NS	$112_{S\downarrow}$	NS	NS	$112_{S\downarrow}$	-	$121_{S\uparrow}$	NS	$233_{S\uparrow}$
W_pA_{RT}	$152_{S\downarrow}$	$233_{S\downarrow}$	NS	$165_{S\downarrow}$	$233_{S\downarrow}$	$121_{S\downarrow}$	-	$116_{S\downarrow}$	$102_{S\uparrow}$
W_pB_{RT}	NS	$117_{S\downarrow}$	NS	NS	$117_{S\downarrow}$	NS	$116_{S\uparrow}$	-	$218_{S\uparrow}$
W_pW_{RT}	$254_{S\downarrow}$	$335_{S\downarrow}$	$159_{S\downarrow}$	$267_{S\downarrow}$	$335_{S\downarrow}$	$335_{S\downarrow}$	$108_{S\downarrow}$	$218_{S\downarrow}$	-

$S\downarrow$ = Significant decrease in Repair Cycle Time (RCT).
$S\uparrow$ = Significant increase in Repair Cycle Time (RCT).
NS = Not significant 0 to 64 hours change in RCT.
A_p = Average parts.
A_{RT} = Average repair team.

B_p = Best parts.
B_{RT} = Best repair team.
W_p = Worst parts.
W_{RT} = Worst repair team.

With this information readily available, any manager or planner could supply Budget Analysts or Congressional Committee members with very real and accurate information.

Chapter VI will present the conclusions of this research study and make recommendations covering ways the Decision Support System developed by this research team may be enhanced.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Overview

The premise of this research was that the time to repair the TF-33 engine at the base level is a major factor in spare engine availability. Since no decision-making tool existed that could aid the manager in his attempt to minimize this repair time, this thesis attempted to develop such a tool. In this chapter, results of our research are reviewed and recommendations for the application and further enhancement of the model are made.

Conclusions

The authors feel that the research objectives of this study were accomplished. The following is a review of those objectives.

Objective One

To develop a valid estimate for the length of the Base Repair Cycle for the TF-33 P7/7A engine.

By developing and verifying a Q-GERT simulation model in Chapter II which depicted the engine repair process, a valid estimate for the length of the Base Repair Cycle was obtained.

Objective Two

To develop a Decision Support System which enables the engine manager to assess the influence on Repair Cycle Time of additional funding levels in specific factor areas.

Using the information from the simulation model in a two-factor ANOVA, the significance of the various factor level combinations was determined. This provided the information needed to build the Resource Allocation Decision Matrix. This decision matrix allowed the manager to answer the question--How will a given percentage change in parts availability affect the Repair Cycle Time of his operation?

Recommendations

The pursuit of the research objectives has produced a number of related topics that may prove to be worthwhile for further study.

1. The critical factor experience level should be quantified. If the relationship between experience level and repair time can be developed, then a more complete model of the Base Repair Cycle can be developed.

2. A cost model should be developed which fully explores the cost tradeoffs of the various alternatives proposed by the matrix built.

3. The Base Repair Cycle model and Resource Allocation Decision Matrix should be expanded to be able to predict repair time for the whole weapon system.

APPENDICES

APPENDIX A

HYPOTHESES -- STATISTICAL TESTS

Statistical Hypothesis 1

Ho: $u \leq u_1 \leq 22$ days

H1: $u > u_1 > 22$ days

$A = u_1 + z_{1-\alpha}(s\bar{x})$

$A = 22 + 2.326(3.121)$

$A = 29.3$ days

If $x \leq A$ then accept Ho; else H1.

u = actual repair time

u_1 = AFM 400-1 standard

= .01 level

$\bar{x}$ = mean repair time for Base level engine repair MAC wide (3 yrs. data)

Since $\bar{x} = 43.9 \leq A = 29.3$, the null hypothesis is rejected. Conclude H1.

Statistical Hypothesis 2

Ho: $u_a = u_b, u_c, u_d, u_e$

H1: one of the mean times differs from u_a

$$d' = tD_{\alpha/2;k,v}\left(\frac{(2(MSE)}{n}\right)^{1/2}$$

$$d' = 3.25\left(\frac{2(54.9)}{13}\right)^{1/2}$$

$$d' = 9.75$$

If $u_a - u_i \leq d'$ then accept Ho; else H1. Since 5.4 was the largest difference the null hypothesis is accepted.

where: u_a = the mean repair time at M^cGuire

u_b = the mean repair time at Charleston

u_c = the mean repair time at Norton

u_d = the mean repair time at Travis

u_e = the mean repair time at M^cChord

α = .01 level

Statistical Hypothesis 3

Ho: $u = u_1 = 44.2$ days

H1: $u \neq u_1 \neq 44.2$ days

$A_1 = u_1 - t_{1-\alpha/2}(sx)$

$A_2 = u_1 + t_{1-\alpha/2}(sx)$

$A_1 = 29.6$ days

$A_2 = 58.8$ days

where: u = the model repair time

u_1 = M^cGuire's repair time

$\bar{x}$ = model sample mean

$\bar{x}$ = 32 days

If $A_1 \leq \bar{x} \leq A_2$ then conclude Ho; else H1.

Since $29.6 \leq 32 \leq 58.8$ then conclude Ho.

APPENDIX B

COMPUTER PROGRAM FOR "BEST" CONDITION

```
GEN,CONN/JOHN,TF33,03,01,81,0,1,400,,10,E*
SOU,1,0,1,D,M*
QUE,2,1,,D,F,,0,0*
SIN,21,1,1,D,I,0,0*
REG,3,1,1,P*
ACT,1,1,EX,1,1,1,1*
PAR,1,96,24,150*
ACT,1,2,CO,0,2,1,1*
ACT,2,3,NO,2,3,1,1*
PAR,2,4.5,4,8,1.5*
ACT,3,4,CO,1,4,1,.9*
ACT,3,5,CO,1,5,1,.1*
REG,4,1,1,D,M*
QUE,5,0,,D,F,,0,0,(10)6*
ACT,4,5,BP,5,66,1,1*
PAR,10,300,240,480*
RES,1/STANDS,12,6*
ALL,6,RAN,1,1,5/7,14/15*
QUE,7,0,,D,F,,0,0,(10)6*
RES,2/MEN,11,8*
ALL,8,RAN,2,1,7/9,15/25*
REG,9,1,1,D*
REG,10,1,1,P,M*
ACT,9,10,NO,3,6/TRWDN,8,1*
PAR,3,120,100,130,10*
ACT,10,11,CO,2,7,1,.4*
FRE,11,D,1,1,6*
ACT,11,12,CO,0,8,1,1*
FRE,12,D,2,1,8*
ACT,12,13,CO,0,9,1,1*
REG,13,1,1,D*
ACT,13,14,BP,4,10/AWLP,1,1*
PAR,4,550,480,900*
QUE,14,15,,D,F,,0,0,(10)6*
QUE,15,0,,D,F,,0,0,(10)8*
REG,25,1,1,D*
ACT,25,16,BP,5,11,8*
PAR,5,320,300,400*
ACT,10,16,BP,6,12/REPAIR,8,.2*
PAR,6,323,303,403*
ACT,10,16,BP,5,13/REPAIR,8,.4*
REG,16,1,1,D*
REG,17,1,1,D*
ACT,16,17,BP,7,14/REASSEMB,8,1*
REG,18,1,1,P*
ACT,17,18,NO,8,15/TESTRUN,1,.1*
ACT,18,17,CO,3.5,16/TRUNFAIL,1,.2*
ACT,18,19,NO,9,17/FINAL,2,.8*
PAR,7,120,100,140*
PAR,8,6,3,12,2*
PAR,9,84,8,90,8*
FRE,19,D,1,1,6*
FRE,20,D,2,1,8*
ACT,19,20,CO,0,18*
ACT,20,21,CO,0,19*
FIN*
```

APPENDIX C

COMPUTER PROGRAM FOR "AVERAGE" CONDITION

```
GEN,CONN/JOHN,TF33,03,21,81,0,1,400,,10,E*
SOU,1,0,1,D,M*
QUE,2,1,,D,F,,0,0*
SIN,21,1,1,D,I,0,0*
REG,3,1,1,P*
ACT,1,1,EX,1,1,1,1*
PAR,1,96,24,150*
ACT,1,2,CO,0,2,1,1*
ACT,2,3,NO,2,3,1,1*
PAR,2,4.5,4,8,1.5*
ACT,3,4,CO,1,4,1,.8*
ACT,3,5,CO,1,5,1,.2*
REG,4,1,1,D,M*
QUE,5,0,,D,F,,0,0,(10)6*
ACT,4,5,BP,5,66,1,1*
PAR,10,300,240,480*
RES,1/STANDS,9,6*
ALL,6,RAN,1,1,5/7,14/15*
QUE,7,0,,D,F,,0,0,(10)8*
RES,2/MEN,8,8*
ALL,8,RAN,2,1,7/9,15/25*
REG,9,1,1,D*
REG,10,1,1,P,M*
ACT,9,10,NO,3,6/TRDWN,8,1*
PAR,3,120,100,130,10*
ACT,10,11,CO,2,7,1,.3*
FRE,11,D,1,1,6*
ACT,11,12,CO,0,8,1,1*
FRE,12,D,2,1,8*
ACT,12,13,CO,0,9,1,1*
REG,13,1,1,D*
ACT,13,14,BP,4,10/AWLP,1,1*
PAR,4,330,170,950*
QUE,14,15,,D,F,,0,0,(10)6*
QUE,15,0,,D,F,,0,0,(10)8*
REG,25,1,1,D*
ACT,25,16,BP,5,11,8*
PAR,5,320,300,400*
ACT,10,16,BP,6,12/REPAIR,8,.4*
PAR,6,323,303,403*
ACT,10,16,BP,5,13/REPAIR,8,.3*
REG,16,1,1,D*
REG,17,1,1,D*
ACT,16,17,BP,7,14/REASSEMB,8,1*
REG,18,1,1,P*
ACT,17,18,NO,8,15/TESTRUN,1,.1*
ACT,18,17,CO,3.5,16/TRENFAIL,1,.2*
ACT,18,19,NO,9,17/FINAL,2,.8*
PAR,7,120,100,140*
PAR,8,6,3,12,2*
PAR,9,84,8,90,8*
FRE,19,D,1,1,6*
FRE,20,D,2,1,8*
ACT,19,20,CO,0,18*
ACT,20,21,CO,0,19*
FIN*
```

APPENDIX D

COMPUTER PROGRAM FOR "WORST" CONDITION

```
GEN,CONN/JOHN,TF33,03,21,81,0,1,400,,10,E*
SOU,1,0,1,D,M*
QUE,2,1,,D,F,,0,0*
SIN,21,1,1,D,I,0,0*
REG,3,1,1,P*
ACT,1,1,EX,1,1,1,1*
PAR,1,96,24,150*
ACT,1,2,CO,0,2,1,1*
ACT,2,3,NO,2,3,1,1*
PAR,2,4.5,4,8,1.5*
ACT,3,4,CO,1,4,1,.7*
ACT,3,5,CO,1,5,1,.3*
REG,4,1,1,D,M*
QUE,5,0,,D,F,,0,0,(10)6*
ACT,4,5,BP,5,66,1,1*
PAR,10,300,240,480*
RES,1/STANDS,6,6*
ALL,6,RAN,1,1,5/7,14/15*
QUE,7,0,,D,F,,0,0,(10)8*
RES,2/MEN,5,8*
ALL,8,RAN,2,1,7/9,15/25*
REG,9,1,1,D*
REG,10,1,1,P,M*
ACT,9,10,NO,3,6/TRWDN,8,1*
PAR,3,120,100,130,10*
ACT,10,11,CO,2,7,1,.2*
FRE,11,D,1,1,6*
ACT,11,12,CO,0,8,1,1*
FRE,12,D,2,1,8*
ACT,12,13,CO,0,9,1,1*
REG,13,1,1,D*
ACT,13,14,BP,4,10/AWLP,1,1*
PAR,4,550,480,900*
QUE,14,15,,D,F,,0,0,(10)6*
QUE,15,0,,D,F,,0,0,(10)8*
REG,25,1,1,D*
```

```
ACT,25,16,BP,5,11,8*
PAR,5,320,300,400*
ACT,10,16,BP,6,12/REPAIR,8,.6*
PAR,6,323,303,403*
ACT,10,16,BP,5,13/REPAIR,8,.2*
REG,16,1,1,D*
REG,17,1,1,D*
ACT,16,17,BP,7,14/REASSEMB,8,1*
REG,18,1,1,P*
ACT,17,18,NO,8,15/TESTRUN,1,.1*
ACT,18,17,CO,3.5,16/TRUNFAIL,1,.2*
ACT,18,19,NO,9,17/FINAL,2,.8*
PAR,7,120,100,140*
PAR,8,6,3,12,2*
PAR,9,84,8,90,8*
FRE,19,D,1,1,6*
FRE,20,D,2,1,8*
ACT,19,20,CO,0,18*
ACT,20,21,CO,0,19*
FIN* BA
```

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Air Force Logistics Command. Contract Proposal RFP F3360080-R-0310 with Systems Control, Inc. Techniques for the Enhancement of Engine Pipeline Standards. Wright-Patterson AFB OH, May 1980.

2. Brannock, Captain James W. Logistic Planning Analyst, Directorate of Propulsion Systems, HQ AFLC, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 31 August 1980 to 31 October 1980.

3. ________, Captain Gary J. Jungsirth, and Chief Master Sergeant Robert M. McChord, USAF. "A Study of Spare Engine Repair Pipelines and Their Impact on Mission Capability." Unpublished report, unnumered, HQ SAC/LGM, Offutt AFB NE, 1977.

4. Clark, Thomas D. Professor, Air Force Institute of Technology, Wright-Patterson AFB OH. Personal interview. 6 November 1980.

5. Geer, John L., Senior Master Sergeant. HQ MAC Training Analysis, Scott AFB IL. Telephone interview. 6 November 1980.

6. Gibbons, Jean Dickinson. Nonparametric Methods for Quantitative Analysis. New York: Holt, Rinehart and Winston, 1976.

7. Ingram, Jess. Air Force Audit Agency, Tinker AFB OK. Personal interview. 23 March 1981.

8. Kehl, Captain Ted L., USAF. "An Analysis of Factors Influencing Spare Engine Management." Unpublished master's thesis. AFIT/GSM/SM/70-10, AFIT/EN, Wright-Patterson AFB OH, November 1970. AD 881694.

9. Kirk, Roger E. Experimental Design: Procedures for the Behavioral Sciences. Belmont CA: Brooks/Cole Publishing Company, 1968.

10. Nelson, J. R. "An Approach to the Life Cycle Analysis of Aircraft Turbine Engines." The Rand Corporation, Santa Monica CA, Report No. N-1337-AF, November 1979.

11. Neter, John, and William Wasserman. Applied Linear Statistical Models. Homewood IL: Richard D. Irwin, Inc., 1974.

12. ________, and G. A. Whitmore. Applied Statistics. 5th ed. Boston: Allyn and Bacon, Inc., 1979.

13. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks. 2d ed. New York: John Wiley and Sons, Inc., 1979.

14. Safran, Nadar. "The War and the Future of the Arab Israeli Conflict," Foreign Affairs, January 1974, pp. 215-236.

15. Schoderbek, Peter P., Asterios G. Kefalas, and Charles G. Schoderbek. Management Systems: Conceptual Considerations. Dallas: Business Publications, Inc., 1980.

16. Shannon, Robert E. Systems Simulation--the Art and Science. Englewood Cliffs NJ: Prentice Hall, Inc., 1975.

17. United Stated Army Air Mobility Research and Development Laboratory. Contract DAAJ02-68-C-0002 with General Electric Company. Reliability, Maintainability, and Logistics Analysis. Wright-Patterson AFB OH, 1973.

18. U.S. Department of the Air Force. D024 Quarterly Pipeline Time Analysis. Data Summary Report, Part 1. Wright-Patterson AFB OH. 1 July 1980-30 September 1980.

19. ________. Selective Management of Propulsion Units. AFM 400-1. Vol. 1. Washington: Government Printing Office, 1976.

B. RELATED SOURCES

Hottenstein, Michael P. Models and Analysis for Production Management. Scranton PA: International Textbook Company, 1968.

Lavalee, Commander William. "Aircraft Engine Maintenance Study." Unpublished technical report, CNS 1060, Center for Naval Analysis, Arlington VA, 1975.

Weifenback, Annette. Base Maintenance Activity and Repair Cycle Times. Rand Corporation Report RM-5027-PR, Santa Monica CA, September 1966. AD 645112.